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ABSTRACT

Investigated was the relationship between proportional thinking and students' ability to demonstrate knowledge and understanding of concepts related to simple machines, structure of matter, and equivalent fractions. The study involved a random sample of 136 ninth-grade physical science students. Each student's proportional reasoning skills were assessed using two Piagetian tasks: the Balance and the Quantifications of Probabilities. The students were classified into four groups according to their proportional reasoning ability. Students' achievement of the selected science and mathematics concepts was assessed at the knowledge, comprehension, and application levels using a paper/pencil test. The study indicated that proportional reasoning appeared to be an underlying factor associated with achievement of simple machines, structure of matter and equivalent fractions concepts among ninth-graders. Achievement of the concepts increased as proportional reasoning increased. Also, as the general level of achievement increased, proportional reasoning appeared to be more critical for understanding subject matter. (Author/GA)

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THE RELATIONSHIP BETWEEN THE PROPORTIONAL REASONING ABILITY OF NINTH GRADERS AND THEIR ACHIEVEMENT OF SELECTED MATH AND SCIENCE CONCEPTS

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Introduction

The Piagetian notion of cognitive development provides a useful theoretical framework with which to analyze the intellectual competence of students and the conceptual requirements of the curriculum (Hartford and Good, 1976). The framework can be used to categorize intellectual growth into a hierarchy of logical thinking skills which appear to underlie the acquisition of subject matter. For example, quantitative proportionality, a logical thinking skill which manifests itself during the stage of formal operations, appears to be necessary for understanding numerous mathematics and science concepts taught in the secondary school. This schema seems to underlie the achievement of numerical relationships and models used to represent theoretical concepts. As such, it would be expected that students would need to possess quantitative proportionality in order to understand the concepts associated with equivalent fractions, simple machines, and the structure of matter.

Science instruction often utilizes models to represent the particulate nature of matter. These models can be viewed as analogies where a theoretical notion is represented by concrete objects or symbols (Pella and Ziegler, 1967). According to Lunzer (1965), verbal analogies have a structre similar to numerical proportions and require formal operational thinking to understand. Understanding simple machines involves coordination of the relationship between the variables of force and distance as they relate to work. Similarly, understanding equivalent fractions involves the coordination of identical part-whole relationships.

If the logical thinking skill of quantitative proportionality is required for understanding simple machines, structure of matter, and equivalent fractions, then students who are at the concrete level with respect to this ability would not be expected to demonstrate understanding of these concepts after studying them in school. In other words, the proportional reasoning skills of concrete operational students would be expected to impose a ceiling which would preclude their understanding the concept. Since the age posited by Piaget for the beginning of formal operational thinking for most children is about 11 or 12, a review of research studies investigating student achievement of the selected concepts should reveal few students below this age level who demonstrate understanding of the concepts.

Anderson (1965) investigated 8-12 year-olds' understanding of the particulate structre of matter and found that only 30% of the students demonstrated understanding of the concept after instruction. Harris (1964) investigated the ability of 9-11 year-old students to understand concepts basic to the molecular theory of heat. He found that less than 50% of the students demonstrated understanding. The grade level at which selected structure of matter concepts could be appropriately taught at the knowledge, comprehension, and application levels of Bloom's taxonomy was investigated by Pella and Carey (1967). These researchers found that many concepts such as "molecules are composed of atoms" and "particles making up matter are in motion" were inappropriate for students 7 to 10 years old. Ward (1973) sought to determine if chronological age is a main factor in a child's ability to develop a particulate concept of matter. He found that children under 10 years of age were unable to develop the abstract conceptualization.

Similar results have been found by researchers investigating students' achievement of equivalent fractions. Novillis (1976) tested 9-12 year old students who had studied equivalent fractions in their regular classroom and found that only 7 percent demonstrated understanding. Steffe & Parr (1968) investigated the understanding of equivalent fractions by 9-12 year old students. After finding that only 50 percent of the students demonstrated understanding, they concluded that formal operational thinking was necessary for understanding equivalent fractions. Coburn (1974) concluded, after testing two different methods of teaching equivalent fractions to 9 and 10 year olds, that equivalent fractions might be inapprorpriate to teach at that age level. He found that only 50 percent of the students achieved the concept.

The purpose of this study was to investigate the relationship between proportional reasoning ability of ninth-grade students and their achievement of simple machines, structure of matter and equivalent fractions concepts. Ninth-grade students were selected for this study because they vary widely in their intellectual development, ranging from low concrete to high formal operational (Chiappetta, 1976). They were also selected because many ninth-grade students are required to take physical science, a course which addresses the concepts of simple machines and the structure of matter.

Achievement of the selected concepts was analyzed at the knowledge, comprehension, and application levels of Bloom's Taxonomy of Educational Objectives. According to Bloom (1956), knowledge is the lowest level of educational objectives that a student can achieve, and it does not represent understanding. Comprehension, the next level of

educational objectives is defined as the first level at which understanding occurs. Application represents understanding at a level just higher than comprehension. Students not possessing quantitative proportionality were expected to achieve knowledge of the selected concepts, but not comprehension or application.

Methods and Procedures

A sample of 136 students (68 boys and 68 girls) was randomly selected from a population of 444 ninth-grade physical science students who were taking physical science as a required course. These students attended a predominately all white, middle class, city high school located in the southwest part of the United States. The school has a population of 2,700 students and the city has a population of about 100,000.

Students' achievement of the selected concepts was assessed at the knowledge comprehension and application levels by three paper and pencil tests. Each test had 36 items: 12 knowledge, 12 comprehension, and 12 application type items. The test consisted of matching and multiple choice items. Students had approximately 80 minutes to complete the three tests and almost all students finished.

The reliability of the instruments was estimated by applying the Kuder-Richardson Formula 20. A reliability estimate was obtained for each instrument and for each of the three sets of 12 items measuring knowledge, comprehension, and application. The reliability estimates for equivalent fractions and structure of matter were .91 and .90 respectively. The reliability estimate for simple machines was .79. The reliabilities for all subtests were greater than .70.

Students' proportional reasoning skills were assessed by application of two Piagetian tasks--The Balance (Inhelder and Piaget, 1958) and The Quantifications of Probabilities (Piaget and Inhelder, 1975). Students were classified as having demonstrated either low qualitative, high qualitative, low quantitative or high quantitative proportionality on each of these tasks. A discriminant function analysis using students' knowledge, comprehension, and application test scores as discriminating variables revealed that the quantifications of probabilities classifications produced the best discrimination between the criterian groups. This classification was therefore employed in the data analysis. Table 1 lists the number of students classified into each of the four criterian groups. Examination of Table 1 reveals that almost half of the students demonstrated low qualitative proportional reasoning and approximately 20 percent of the students demonstrated quantitiative proportional reasoning ability.

The science and mathematics instruments were administered to students by a tester during their regular physical science period. All testing was done on the same day. The methods and procedures for test administration were standardized by the researchers. The Piagetian tasks were administered to each student on an individual basis.

Results

The mean scores for the students at the four levels of proportional reasoning ability for the selected concepts are given in Table 2. Examination of the table reveals two expected patterns. First, group means are generally highest for knowledge and lowest for application test items, with comprehension test item means falling in between. Second, the magnitude of the group means generally follows the level of proportional reasoning; the higher the level of proportional reasoning ability, the higher the group means.

The Wilks' lambda test was employed to determine if the four proportionality groups differed significantly over the three levels of achievement for each of the selected concepts. This test was significant at the $p \leq .01$ level, indicating different levels of achievement were demonstrated by the groups (Table 3).

Separate discriminant function analyses were applied to the simple machines, structure of matter, and equivalent fraction data. When applied to the simple machines data, knowledge and application test scores significantly discriminated between the groups and produced two discriminate function equations as shown in Table 4. Examination of the discriminant function coefficients in the primary equation (function 1) reveals that the discriminating power of knowledge scores contributed almost twice as much discrimination than the application scores. The prediction equations correctly classified 42.96 percent of the students (Table 5).

Knowledge and comprehension scores for structure of matter significantly discriminated between the four groups and produced two discriminant function equations (Table 4). The discriminating

power of knowledge scores was about four times greater than the comprehension scores. The prediction equations correctly classified 44.44 percent of the students (Table 5).

When discriminant function analysis was applied to the equivalent fractions data, only application scores significantly discriminated between the groups. The discriminant function equation generated (Table 4) correctly classified 39.30 percent of the students (Table 5).

Discussion and Conclusions

The hypothesis underlying this study is that a direct relationship exists between proportional reasoning and the understanding of abstract science and mathematics concepts. The data supports this hypothesis and adds credance to the notion that specific logical thinking skills or schema contribute to the achievement of specific concepts. Proportional reasoning appears to be directly related to ninth-grade students' understanding of simple machines, structure of matter and equivalent fractions concepts, with application level test items being better descriminators of proportional reasoning ability than comprehension level test items. However, much to the surprise of the researchers, knowledge level test items were found to be the best discriminators of proportional reasoning ability.

Knowledge, rather than comprehension or application, was found to be the primary discriminating variable for the science concepts. This unexpected relationship between knowledge and proportional reasoning might be attributed to the low level of achievement that was demonstrated by the students on these concepts. The data suggets

that when students have learned very little information or knowledge about a concept, their proportional reasoning ability will interact with learning the concept at the lowest level of cognitive activity as defined by Bloom's Taxonomy. Possibly, in the initial phase of learning an abstract concept logical thinking ability is very important for making meaning out of factual information and retaining this information. Conversely, when students have learned a substantial amount of information, as was the case with equivalent fractions, their proportional reasoning ability will interact with learning a concept at the higher levels of cognitive activity as defined by Bloom's Taxonomy.

In conclusion, proportional reasoning appears to be an underlying factor associated with achievement of simple machines, structure of matter and equivalent fractions concepts among ninth-graders. Achievement of the concepts increases as proportional reasoning increases. Also, as the general level of achievement increases, proportional reasoning appears to be more critical for understanding subject matter.

Table 1

PERCENTAGES OF NINTH-GRADERS AT EACH OF THE PROPORTIONAL REASONING LEVELS

Level	Percent
Low qualitative	48.5
High qualitative	31.6
Low quantitative	11.8
High quantitative	8.1

Table 2

MEAN SCORES AT FOUR LEVELS OF

PROPORTIONAL REASONING ABILITY FOR THE SELECTED CONCEPTS

Proportional Reasoning Level	Simple Machines		
	Knowledge	Comprehension	Application
Low Qualitative	6.82	6.62	3.74
High Qualitative	8.36	7.38	3.98
Low Quantitative	9.50	8.19	3.00
High Quantitative	9.64	9.27	6.64
Proportional Reasoning Level	**Structure of Matter**		
	Knowledge	Comprehension	Application
Low Qualitative	5.70	6.32	4.62
High Qualitative	7.17	6.90	4.50
Low Quantitative	8.50	7.19	5.06
High Quantitative	9.91	9.45	6.18
Proportional Reasoning Level	**Equivalent Fractions**		
	Knowledge	Comprehension	Application
Low Qualitative	9.41	9.24	5.97
High Qualitative	9.55	9.19	6.45
Low Quantitative	10.31	11.31	8.94
High Quantitative	11.73	11.73	10.27

Table 3

WILK'S LAMBDA TEST FOR SIGNIFICANT DIFFERENCES BETWEEN LEVEL OF PROPORTIONAL REASONING AND LEVEL OF ACHIEVEMENT

Selected Concepts	Wilk's Lambda Test	chi-square	df	significance
Simple Machines	.7440	38.736	6	.01
Structure of Matter	.8068	28.123	6	.01
Equivalent Fractions	.7768	33.210	3	.01

Table 4

DISCRIMINANT PREDICTION EQUATIONS

Selected Concepts	Function 1	Function 2
Simple Machines	$D = .7935\ X_K + .4877X_A$	$D = -.5325X_K + .7531X_A$
Structure of Matter	$D = .7962X_K + .1802X_C$	$D = -.4577X_K + .6304X_C$
Equivalent Fractions	$D = 1.000X_A$	

K = Knowledge

A = Application

C = Comprehension

Table 5

PERCENT OR STUDENTS CORRECTLY
CLASSIFIED BY DISCRIMINANT FUCTION ANALYSIS

Concepts	Percent correctly classified %
Simple Machines	42.96
Structure of Matter	44.44
Equivalent Fractions	39.36

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